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(54) IMPROVED SAMPLE INSPECTION SYSTEM

VERBESSERTES PRÜFSYSTEM FÜR PROBEN

SYSTEME D'INSPECTION D'ECHANTILLON AMELIORE

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(56) References cited:
EP-A- 0 624 787
WO-A-97/33158
US-A- 4 449 818
US-A- 4 929 845
US-A- 5 424 838
US-A- 5 798 829
WO-A-97/12226
DE-A- 4 123 916
US-A- 4 893 932
US-A- 5 058 982
US-A- 5 650 614

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Description

[0001] This invention relates in general to sample inspection systems and, in particular, to an improved inspection system with good sensitivity for particles as well as crystal-originated-particles (COPs). COPs are surface breaking defects in semiconductor wafers which have been classified as particles due to inability of conventional inspection systems to distinguish them from real particles.

[0002] Systems for inspecting unpatterned wafers or bare wafers have been proposed-see for example, WO 97/12226 entitled "Improved System for Surface Inspection". Systems such as those described in the above-referenced application are useful for many applications, including the inspection of bare or unpatterned semiconductor wafers. Nevertheless, it may be desirable to provide improved sample inspection tools which may be used for inspecting not only bare or unpatterned wafers but also rough films. Another issue which has great significance in wafer inspection is that of COPs. These are surface-breaking defects in the wafer. According to some opinions in the wafer inspection community, such defects can cause potential detriments to the performance of semiconductor chips made from wafers with such defects. It is, therefore, desirable to provide an improved sample inspection system capable of detecting COPs and distinguishing COPs from particles.

[0003] An optical scanning system according to the preamble of claim 1 is known from US 5,650,614. A combined bright and dark field sample inspection which uses a curved mirror to collect scattered light is described in WO 97/33158. Background prior art is described in US 5,058,982 and US 4,449,818.

SUMMARY OF THE INVENTION

[0004] This invention is based on the observation that anomaly detection employing an oblique illumination beam is much more sensitive to particles than to COPs, whereas in anomaly detection employing an illumination beam normal to the surface, the difference in sensitivity to surface particles and COPs is not as pronounced. Anomaly detection employing both an oblique illumination beam and a normal illumination beam can then be used to distinguish between particles and COPs.

[0005] The invention is directed towards an optical system for detecting anomalies of a sample, comprising first means for directing a first beam of radiation along a first path onto a first spot on a surface of the sample; second means for directing a second beam of radiation along a second path onto a second spot on a surface of the sample, said first and second paths being at different angles of incidence to said surface of the sample; and a first detector; characterised by means including a curved mirrored surface configured to receive scattered radiation from the first or the second spot on the sample surface originating from the first or second beam, and to focus the scattered radiation to said first detector; and in that said first detector is a non-imaging detector configured to provide an output in response to the total radiation focussed onto it.

[0006] In another aspect the invention provides an optical method for detecting anomalies of a sample comprising directing a first beam of radiation along a first path onto a first spot on the surface of the sample; and directing a second beam of radiation along a second path onto a second spot on the surface of the sample, said first and second paths being at different angles of incidence to said surface of the sample; and characterised by employing a curved mirrored surface to receive scattered radiation from the first or second spot on the sample surface, originating from the first or second beam and focusing the scattered radiation to a first non-imaging detector, and outputting a signal from said non-imaging detector in response to the total radiation focussed onto it by said curved mirrored surface.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007]

Figs. 1A, 1B and 1C are schematic views of normal or oblique illumination beams illuminating a surface with a particle thereon useful for illustrating the invention.

Fig. 2A is a schematic view of a sample inspection system employing an ellipsoidal mirror for illustrating one embodiment of the invention.

Fig. 2B is a schematic view of a sample inspection system employing a paraboloidal mirror to illustrate another embodiment of the invention.

Fig. 3 is an exploded simplified view of a portion of the system of Fig. 2A or Fig. 2B to illustrate another aspect of the invention.

Fig. 4 is a schematic view of a sample inspection system employing two different wavelengths for illumination to illustrate yet another embodiment of the invention.

Figs. 5A and 5B are schematic views of sample inspection systems illustrating two different embodiments employing switches for switching a radiation beam between a normal illumination path and an oblique illumination path to illustrate yet another aspect of the invention.

Fig. 6 is a schematic view of a beam illuminating a semiconductor wafer surface to illustrate the effect of a change in height of a wafer on the position of the spot illuminated by beam.

Fig. 7 is a schematic view of a portion of a sample inspection system inspecting a semiconductor wafer, employing three lenses, where the direction of the illumination beam is altered to reduce the error in the position of the illuminated spot caused by the change in height of the wafer.

Fig. 8 is a schematic view of a portion of a sample inspection system employing only one lens to compensate for a change in height of the wafer.

Figs. 9A-9F are schematic views of six different spatial filters useful for detecting anomalies of samples.

Fig. 10A is a simplified partially schematic and partially cross-sectional view of a programmable spatial filter employing a layer of liquid crystal material sandwiched between an electrode and an array of electrodes in the shape of sectors of a circle and means for applying a potential difference across at least one sector in the array and the other electrode, so that the portion of the liquid crystal layer adjacent to the at least one sector is controlled to be radiation transparent or scattering.

Fig. 10B is a top view of the filter of Fig. 10A.

Fig. 11 is a schematic view of a sample inspection system employing an oblique illumination beam and two detectors for distinguishing between COPs and particles to illustrate another aspect of the invention.

[0008] For simplicity in description, identical components are labelled by the same numerals in this application.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0009] Fig. 1A is a schematic view of a surface 20 of a sample to be inspected and an illumination beam 22 directed in a direction normal to surface 20 to illuminate the surface and a particle 24 on the surface. Thus, the illumination beam 22 illuminates an area or spot 26 of surface 20 and a detection system (not shown) detects light scattered by particle 24 and by portion or spot 26 of the surface 20. The ratio of the photon flux received by the detector from particle 24 to that from spot 26 indicates the sensitivity of the system to particle detection.

[0010] If an illumination beam 28 directed at an oblique angle to surface 20 is used to illuminate spot 26' and particle 24 instead, as shown in Fig. 1B, from a comparison between Figs. 1A and 1B, it will be evident that the ratio of the photon flux from the particle 24 to that from the illuminated spot will be greater in the case of the oblique illumination in Fig. 1B compared to that in Fig. 1A. Therefore, for the same throughput (spots 26, 26' having the same area), the sensitivity of the oblique incidence beam in detecting small particles is superior and is the method of choice in the detection of small particles.

[0011] Fig. 1C illustrates an oblique beam 28' illuminating a surface 30 having a pit 32 and particle 24' thereon. As can be seen from Fig. 1C, even though the pit 32 is of comparable size to particle 24, it will scatter a much smaller amount of photon flux compared to particle 24 from oblique beam 28'. On the other hand, if the pit 32 and particle 24 are illuminated by a beam such as 22 directed in a direction normal to surface 30, pit 32 and particle 24 would cause comparable amount of photon flux scattering. Almost regardless of the exact shape or orientation of COPs and particles, anomaly detection employing oblique illumination is much more sensitive to particles than COPs. In the case of anomaly detection with normal illumination, however, the differentiation between particles and COPs is less pronounced. Therefore, by means of a simultaneous, or sequential, comparison of feature signatures due to normal and oblique illumination will reveal whether the feature is a particle or a COP.

[0012] Azimuthal collection angle is defined as the angle made by the collection direction to the direction of oblique illumination when viewed from the top. By employing oblique illumination, together with a judicious choice of the azimuthal collection angle, rough films can be inspected with good sensitivity, such as when a spatial filter shown in any of Figs. 9A-9F, 10A and 10B is used in any one of the embodiments as shown in Figs. 2A, 2B, 3, 4, 5A and 5B, as explained below. By retaining the normal illumination beam for anomaly detection, all of the advantageous attributes of the system described in PCT Patent Application No. PCT/US96/15354 noted above, are retained, including its uniform scratch sensitivity and the possibility of adding a bright-field channel as described in PCT Patent Application No. PCT/US97/04134, filed March 5, 1997, entitled "Single Laser Bright Field and Dark Field System for Detecting Anomalies of a Sample."

[0013] Scanning a sample surface with oblique and normal illumination beams can be implemented in a number of ways. Fig. 2A is a schematic view of a sample inspection system to illustrate a general set up for implementing anomaly detection using both normal and oblique illumination beams. A radiation source that provides radiation at one or more wavelengths in a wide electromagnetic spectrum (including but not limited to ultraviolet, visible, infrared) may be used, such as a laser 52 providing a laser beam 54. A lens 56 focuses the beam 54 through a spatial filter 58 and lens 60 collimates the beam and conveys it to a polarizing beamsplitter 62. Beamsplitter 62 passes a first polarized component to the normal illumination channel and a second polarized component to the oblique illumination channel, where the first and second components are orthogonal. In the normal illumination channel 70, the first polarized component is focused by optics 72 and reflected by mirror 74 towards a sample surface 76a of a semiconductor wafer 76. The radiation scattered by surface 76a is collected and focused by an ellipsoidal mirror 78 to a photomultiplier tube 80.

[0014] In the oblique illumination channel 90, the second polarized component is reflected by beamsplitter 62 to a mirror 82 which reflects such beam through a half-wave plate 84 and focused by optics 86 to surface 76a. Radiation originating from the oblique illumination beam in the oblique channel 90 and scattered by surface 76a is collected by an ellipsoidal mirror and focused to photomultiplier tube 80. Photomultiplier tube 80 has a pinhole entrance 80a. The pinhole 80a and the illuminated spot (from the normal and oblique illumination channels on surface 76a) are preferably at the foci of the ellipsoidal mirror 78.

[0015] Wafer 76 is rotated by a motor 92 which is also moved linearly by transducer 94, and both movements are controlled by a controller 96, so that the normal and oblique illumination beams in channels 70 and 90 scan surface 76a along a spiral scan to cover the entire surface.

[0016] Instead of using an ellipsoidal mirror to collect the light scattered by surface 76a, it is also possible to use other curved mirrors, such as a paraboloidal mirror 78' as shown in system 100 of Fig. 2B. The paraboloidal mirror 78' collimates the scattered radiation from surface 76a into a collimated beam 102 and the collimated beam 102 is then focused by an objective 104 and through an analyzer 98 to the photomultiplier tube 80. Aside from such difference, the sample inspection system 100 is exactly the same as system 50 of Fig. 2A. Curved mirrored surfaces having shapes other than ellipsoidal or paraboloidal shapes may also be used; preferably, each of such curved mirrored surfaces has an axis of symmetry substantially coaxial with the path of the normal illumination path, and defines an input aperture for receiving scattered radiation. All such variations are within the scope of the invention. For simplicity, the motor, transducer and control for moving the semiconductor wafer has been omitted from Fig. 2B and from Figs. 4, 5A, 5B described below.

[0017] The general arrangements shown in Figs. 2A and 2B can be implemented in different embodiments. Thus, in one arrangement referred to below as the "GO and RETURN" option, a half-wave plate (not shown) is added between laser 52 and lens 56 in Figs. 2A and 2B so that the polarization of the light reaching the beamsplitter 62 can be switched between P and S. Thus, during the Go cycle, the beamsplitter 62 passes radiation only into the normal channel 70 and no radiation will be directed towards the oblique channel 90. Conversely, during the RETURN cycle, beamsplitter 62 passes radiation only into the oblique channel 90 and no radiation will be directed through the normal channel 70. During the GO cycle, only the normal illumination beam 70 is in operation, so that the light collected by detector 80 is recorded as that from normal illumination. This is performed for the entire surface 76a where motor 92, transducer 94 and control 96 are operated so that the normal illumination beam 70 scans the entire surface 76a along a spiral scan path.

[0018] After the surface 76a has been scanned using normal illumination, the half-wave plate between laser 52 and lens 56 causes radiation from laser 52 to be directed only along the oblique channel 90 and the scanning sequence by means of motor 92, transducer 94 and control 96 is reversed and data at detector 80 is recorded in a RETURN cycle. As long as the forward scan in the GO cycle and the reverse scan in the RETURN cycle are exactly registered, the data set collected during the GO cycle and that collected during the return cycle may be compared to provide information concerning the nature of the defects detected. Instead of using a half-wave plate and a polarizing beamsplitter as in Fig. 2A, the above-described operation may also be performed by replacing such components with a removable mirror placed in the position of beamsplitter 62. If the mirror is not present, the radiation beam from laser 52 is directed along the normal channel 70. When the mirror is present, the beam is then directed along the oblique channel 90. Such mirror should be accurately positioned to ensure exact registration of the two scans during the GO and RETURN cycles. While simple, the above-described GO and RETURN option requires extra time expended in the RETURN cycle.

[0019] The normal illumination beam 70 illuminates a spot on surface 76a. The oblique illumination beam 90 also illuminates a spot on the surface 76a. In order for comparison of data collected during the two cycles to be meaningful, the two illuminated spots should have the same shape. Thus, if beam 90 has a circular crosssection, it would illuminate an elliptical spot on the surface. In one embodiment, focusing optics 72 comprises a cylindrical lens so that beam 70 has an elliptical crosssection and illuminates also an elliptical spot on surface 76a.

[0020] To avoid having to scan surface 76a twice, it is possible to intentionally introduce a small offset between the illuminated spot 70a from normal illumination beam 70 (referred to herein as "normal illumination spot" for simplicity) and the illuminated spot 90a from oblique illumination beam 90 (referred to herein as "oblique illumination spot" for simplicity) as illustrated in Fig. 3. Fig. 3 is an enlarged view of surface 76a and the normal and oblique illumination beams 70, 90 to illustrate an offset 120 between the normal and oblique illumination spots 70a, 90a. In reference to Figs. 2A, 2B, radiation scattered from the two spots 70a, 90a would be detected at different times and would be distinguished.

[0021] The method illustrated in Fig. 3 causes a reduction in system resolution and increased background scattering due to the presence of both spots. In other words, in order that radiation scattered from both spots separated by an offset would be focused through pinhole 80a, the pinhole should be somewhat enlarged in the direction of the offset. As a consequence, detector 80 will sense an increased background scattering due to the enlargement of the pinhole 80a. Since the background is due to both beams whereas the particle scattered radiation is due to one or the other spot, the signal-to-noise ratio is decreased. Preferably, the offset is not greater than three times the spatial extent, or less than the spatial extent, of the point spread function of either the normal or oblique illumination beam. The method illustrated in Fig. 3, however, is advantageous since throughput is not adversely affected compared to that described in PCT Application No. PCT/US96/15354 and the Censor ANS series of inspection systems from KLA-Tencor Corporation of San Jose, California, the assignee of this application.

[0022] Fig. 4 is a schematic view of a sample inspection system employing a normal illumination beam comprising radiation at a first wavelength λ_1 and an oblique illumination beam of radiation of wavelength λ_2 to illustrate another embodiment of the invention. The laser 52 of Figs. 2A, 2B may supply radiation at only one wavelength, such as 488 nm of argon. Laser 52' of Fig. 4 supplies radiation at at least two different wavelengths in beam 54', such as at 488 and 514 nm, instead of radiation of only one wavelength. Such beam is split by a dichroic beamsplitter 162 into a first beam at a first wavelength λ_1 (488 nm) and a second beam of wavelength λ_2 (514 nm), by passing radiation at wavelength λ_1 and reflecting radiation at wavelength λ_2, for example. After being focused by optics 72, beam 70' at wavelength λ_1 is reflected by mirror 74 towards surface 76a as the normal illumination beam. The reflected radiation of wavelength λ_2 at beamsplitter 162 is further reflected by mirror 82 and focused by optics 86 as the oblique illumination beam 90' to illuminate the surface. The optics in both the normal and oblique illumination paths are such that the normal and oblique illuminated spots substantially overlap with no offset there between. The radiation scattered by surface 76a retains the wavelength characteristics of the beams from which the radiation originate, so that the radiation scattered by the surface originating from normal illumination beam 70' can be separated from radiation scattered by the surface originating from oblique illumination beam 90'. Radiation scattered by surface 76a is again collected and focused by an ellipsoidal mirror 78 through a pinhole 164a of a spatial filter 164 to a dichroic beamsplitter 166. In the embodiment of Fig. 4, beamsplitter 166 passes the scattered radiation at wavelength λ_1 to detector 80(1) through a lens 168. Dichroic beamsplitter 166 reflects scattered radiation at wavelength λ_2 through a lens 170 to photomultiplier tube 80(2). Again, the mechanism for causing the wafer to rotate along a spiral path has been omitted from Fig. 4 for simplicity.

[0023] Instead of using a laser that provides radiation at a single wavelength, the laser source 52' should provide radiation at two distinct wavelengths. A commercially available multi-line laser source that may be used is the 2214-65-ML manufactured by Uniphase, San Jose, California. The amplitude stability of this laser at any given wavelength is around 3.5%. If such a laser is used, the scheme in Fig. 4 will be useful for applications such as bare silicon inspection but may have diminished particle detection sensitivity when used to scan rough films.

[0024] Yet another option for implementing the arrangements generally shown in Figs. 2A and 2B is illustrated in Figs. 5A and 5B. In such option, a radiation beam is switched between the normal and oblique illumination channels at a higher frequency than the data collection rate so that the data collected due to scattering from the normal illumination beam may be distinguished from data collected from scattering due to the oblique illumination channel. Thus as shown in Fig. 5A, an electro-optic modulator (e.g. a Pockels cell) 182 is placed between laser 52 and beamsplitter 62 to modulate the radiation beam 54 at the half-wave voltage. This results in the beam being either transmitted or reflected by the polarizing beamsplitter 62 at the drive frequency of modulator 182 as controlled by a control 184.

[0025] The electro-optic modulator may be replaced by a Bragg modulator 192 as shown in Fig. 5B, which may be turned on and off at a high frequency as controlled. Modulator 192 is powered by block 193 at frequency ω_b. This block is turned on and off at a frequency ω_m. In the off condition, a zero order beam 194a passes through the Bragg modulator 192, and becomes the normal illumination beam reflected to surface 76a by mirror 74. In the on condition, cell 192 generates a deflected first order beam 194b, which is reflected by mirrors 196, 82 to surface 76a. However, even though most of the energy from cell 192 is directed to the oblique first order beam, a weak zero order normal illumination beam is still maintained, so that the arrangement in Fig. 5B is not as good as that in Fig. 5A.

[0026] Preferably, the electro-optic modulator of Fig. 5A and the Bragg modulator of Fig. 5B are operated at a frequency higher than the data rate, and preferably, at a frequency at least about 3 or 5 times the data rate of tube 80. As in Fig. 4, the optics in both the normal and oblique illumination paths of Figs. 5A, 5B are such that the normal and oblique illuminated spots substantially overlap with no offset there between. The arrangements in Figs. 2A, 2B, 4, 5A, 5B are advantageous in that the same radiation collector 78 and detector 80 are used for detecting scattered light originating from the normal illumination beam as well as from the oblique illumination beam. Furthermore, by employing a curved surface that collects radiation that is scattered within the range of at least 25 to 70° from a normal direction to surface 76a and focusing the collected radiation to the detector, the arrangements of Fig. 2A, 2B, 4, 5A, 5B maximize the sensitivity of detection.

[0027] In contrast to arrangements where multiple detectors are placed at different azimuthal collection angles relative to the oblique illumination beam, the arrangements of Fig. 2A, 2B has superior sensitivity and is simpler in arrangement and operation, since there is no need to synchronize or correlate the different detection channels that would be required in a multiple detector arrangement. The ellipsoidal mirror 78 collects radiation scattered within the range of at least 25 to 70° from the normal direction to the surface which accounts for most of the radiation that is scattered by surface 76a from an oblique illumination beam, and that contains information useful for particle and COPs detection.

[0028] The three dimensional intensity distribution of scattered radiation from small particles on the surface when the surface is illuminated by a P-polarized illumination beam at or near a grazing angle to the surface has the shape of a toroid. In the case of large particles, higher scattered intensity is detected in the forward direction compared to other directions. For this reason, the curved mirror collectors of Figs. 2A, 2B, 4, 5A, 5B are particularly advantageous for collecting the scattered radiation from small and large particles and directing the scattered radiation towards a detector. In the case of normal illumination, however, the intensity distribution of radiation scattered from small particles on surfaces is in the shape of a sphere. The collectors in Figs. 2A, 2B, 4, 5A, 5B are also advantageous for collecting such scattered radiation. Preferably, the illumination angle of beam 90 is within the range of 45 to 85° from a normal direction to the sample surface, and preferably at 70 or 75°, which is close to the principal angle of silicon at 488 and 514 nm, and would allow the beam passage to be unhindered by the walls of the collector. By operating at this shallow angle, the particle photon flux is enhanced as illustrated in Figs. 1A and 1B and the discrimination against the pits is substantial.

Beam Position Correction

[0029] A prerequisite for the comparison of signals generated by two detection channels for a given defect is the ability to place the two spots on the same location. In general, semiconductor wafers or other sample surfaces are not completely flat, nor do they have the same thickness. Such imperfections are of little concern for anomaly detection employing a normal incidence beam, as long as the wafer surface remains within the depth of focus. In the case of the oblique illumination beam, however, wafer-height variation will cause the beam position and hence the position of the illuminated spot to be incorrect. In Fig. 6, θ is the oblique incidence angle between the beam and a normal direction N to the wafer surface. Thus, as shown in Fig. 6, if the height of the wafer surface moves from the dotted line position 76a' to the solid line position 76a which is higher than the dotted line position by the height h, then the position of the illuminated spot on the wafer surface will be off by an error of w given by $h.\tan\theta$. One possible solution is to detect the change in height of the wafer at the illuminated spot and move the wafer in order to maintain the wafer at a constant height at the illuminated spot, as described in U.S. Patent No. 5,530,550. In the embodiment described above, the wafer is rotated and translated to move along a spiral scan path so that it may be difficult to also correct the wafer height by moving the wafer while it is being rotated along such path. Another alternative is to move the light source and the detector when the height of the wafer changes so as to maintain a constant height between the light source and the detector on the one hand and the wafer surface at the illuminated spot on the other. This is obviously cumbersome and may be impractical. Another aspect of the invention is based on the observation that, by changing the direction of the illumination beam in response to a detected change in wafer height, it is possible to compensate for the change in wafer height to reduce beam position error caused thereby.

[0030] One scheme for implementing the above aspect is illustrated in Fig. 7. As shown in system 200 of Fig. 7, an illumination beam is reflected by a mirror 202 and focused through three lenses L_1, L_2, L_3 to the wafer surface 204a. The positions of the lenses are set in order to focus an oblique illumination beam 70" to wafer surface 204a in dotted line in Fig. 7. Then a quad cell (or other type of position sensitive detector) 206 is positioned so that the specular reflection 70a" of the beam 70" from surface 204 reaches the cell at the null or zero position 206a of the cell. As the wafer surface moves from position 204a to 204b shown in solid line in Fig. 7, such change in height of the wafer causes the specular reflection to move to position 70b", so that it reaches the cell 206 at a position on the cell offset from the null position 206a. Detector 206 may be constructed in the same manner as that described in U.S. Patent No. 5,530,550. A position error signal output from detector 206 indicating the deviation from the null position in two orthogonal directions is sent by cell 206 to a control 208 which generates an error signal to a transducer 210 for rotating the mirror 202 so that the specular reflection 70b" also reaches the cell at the null position 206a. In other words, the direction of the illumination beam is altered until the specular reflection reaches the cell at null position, at which point control 208 applies no error signal to the transducer 210.

[0031] Instead of using three lenses, it is possible to employ a single lens as shown in Fig. 8, except that the correct placement of the illuminated spot on the wafer corresponds not to a null in the position sensing signal from the position sensitive detector, but corresponds to an output of the detector reduced by ½. This approach is shown in Fig. 8. Thus, controller 252 divides by 2 the amplitude of the position sensing signal at the output of quad cell detector 254 to derive a quotient signal and applies the quotient signal to transducer 210. The transducer 210 rotates the mirror by an amount proportional to the amplitude of the quotient signal. The new position of the specular reflection corresponds to the correct location of the spot. The new error signal is now the new reference.

[0032] The above described feature of reducing beam position error of the oblique illumination beam in reference to Figs. 7 and 8 may be used in conjunction with any one of the inspection systems of Figs. 2A, 2B, 3, 4, 5A and 5B, although only the quad cell (206 or 254) is shown in these figures.

Spatial Filter

[0033] In reference to the embodiments of Figs. 2A, 2B, 4, 5A and 5B, it is noted that the radiation collection and detection schemes in such embodiments retain the information concerning the direction of scattering of the radiation from surface 76a relative to the oblique illumination channel 90 or 90'. This can be exploited for some applications such as rough surface inspection. This can be done by employing a spatial filter which blocks the scattered radiation collected by the curved mirrored surface towards the detector except for at least one area have a wedge shape. With respect to the normal illumination channel, there is no directional information since both the illumination and scattering are symmetrical about a normal to the surface. In other words, if the normal illumination channel is omitted in the embodiments of Figs. 2A, 2B, 4, 5A and 5B, the curved mirrored collector 78 or 78' advantageously collects most of the radiation scattered within the toroidal intensity distribution caused by particle scattering to provide an inspection tool of high particle sensitivity. At the same time, the use of a curved mirrored collector retains the directional scattering information, where such information can be retrieved by employing a spatial filter as described below.

[0034] Figs. 9A-9F illustrate six different embodiments of such spatial filters in the shape of butterflies each with two wings. The dark or shaded areas (wings) in these figures represent areas that are opaque to or scatters radiation, and the white or unshaded areas represent areas that transmit such radiation. The size(s) of the radiation transmissive (white or unshaded) area(s) are determined in each of the filters in Figs. 9A-9F by the wedge angle α. Thus, in Fig. 9A, the wedge angle is 10°, whereas in Fig. 9B, it is 20°.

[0035] Thus, if the filter in Fig. 9B is placed at position 300 of Fig. 2A, 2B, 4, 5A or 5B where the 20° wedge-shaped area of radiation collection is centered at approximately 90° and 270° azimuthal collection angles relative to the oblique illumination direction, this has the effect of generating a combined output from two detectors, each with a collection angle of 20°, one detector placed to collect radiation between 80 to 100° azimuthal angles as in U.S. Patent No. 4,898,471, and the other detector to collect radiation between 260 and 280° azimuthal angles. The detection scheme of U.S. Patent No. 4,898,471 can be simulated by blocking out also the wedge area between 260 and 280 azimuthal angles. The arrangement of this application has the advantage over U.S. Patent No. 4,898,471 of higher sensitivity since more of the scattered radiation is collected than in such patent, by means of the curved mirror collector 78, 78'. Furthermore, the azimuthal collection angle can be dynamically changed by programming the filter at position 300 in Figs. 2A, 2B, 4, 5A, 5B without having to move any detectors, as described below.

[0036] It is possible to enlarge or reduce the solid angle of collection of the detector by changing α. It is also possible to alter the azimuthal angles of the wedge areas. These can be accomplished by having ready at hand a number of different filters with different wedge angles such as those shown in Figs. 9A-9F, as well as filters with other wedge shaped radiation transmissive areas, and picking the desired filter and the desired position of the filter for use at position 300 in Figs. 2A, 2B, 4, 5A, 5B. The spatial filters in Figs. 9A-9E are all in the shape of butterflies with two wings, where the wings are opaque to, or scatter, radiation and the spaces between the wings transmit radiation between the mirrored surfaces and detector 80. In some applications, however, it may be desirable to employ a spatial filter of the shape shown in Fig. 9F having a single radiation transmissive wedge-shaped area. Obviously, spatial filters having any number of wedge-shaped areas that are radiation transmissive dispersed around a center at various different angles may also be used and are within the scope of the invention.

[0037] Instead of storing a number of filters having different wedge angles, different numbers of wedges and distributed in various configurations, it is possible to employ a programmable spatial filter where the opaque or scattering and transparent or transmissive areas may be altered. For example, the spatial filter may be constructed using corrugated material where the wedge angle α can be reduced by flattening the corrugated material. Or, two or more filters such as those in Figs. 9A-9F may be superimposed upon one another to alter the opaque or scattering and transparent or transmissive areas.

[0038] Alternatively, a liquid crystal spatial filter may be advantageously used, one embodiment of which is shown in Figs. 10A and 10B. A liquid crystal material can be made radiation transmissive or scattering by changing an electrical potential applied across the layer. The liquid crystal layer may be placed between a circular electrode 352 and an electrode array 354 in the shape of n sectors of a circle arranged around a center 356, where n is a positive integer. The sectors are shown in Fig. 10B which is a top view of one embodiment of filter 350 in Fig. 10A Adjacent electrode sectors 354(i) and 354(i+1), i ranging from 1 to n-1, are electrically insulated from each other.

[0039] Therefore, by applying appropriate electrical potentials across one or more of the sector electrodes 354(i), where (i) ranges from 1 to n, on one side, and electrode 352 on the other side, by means of voltage control 360, it is possible to programmably change the wedge angle α by increments equal to the wedge angle β of each of the sector electrodes 354(1) through 354 (n). By applying the potentials across electrode 352 and the appropriate sector electrodes, it is also possible to achieve filters having different numbers of radiation transmissive wedge-shaped areas disposed in different configurations around center 356, again with the constraint of the value of β. To simplify the drawings, the electrical connection between the voltage control 360 and only one of the sector electrodes is shown in Figs. 10A and 10B. Instead of being in the shape of sectors of a circle, electrodes 354 can also be in the shape of triangles. Where electrodes 354 are shaped as isosceles triangles, the array of electrodes 354 arranged around center 356 has the shape of a polygon. Still other shapes for the array 354 are possible.

[0040] If the wedge angle β is chosen to be too small, this means that an inordinate amount of space must be devoted to the separation between adjacent sector electrodes to avoid electrical shorting. Too large a value for β means that the wedge angle α can only be changed by large increments. Preferably β is at least about 5°.

[0041] For the normal illumination beam, the polarization state of the beam does not, to first order, affect detection. For the oblique illumination beam, the polarization state of the beam can significantly affect detection sensitivity. Thus, for rough film inspection, it may be desirable to employ S polarized radiation, whereas for smooth surface inspection, S or P polarized radiation may be preferable. After the scattered radiation from the sample surface originating from each of the two channels have been detected, the results may be compared to yield information for distinguishing between particles and COPs. For example, the intensity of the scattered radiation originating from the oblique channel (e.g., in ppm) may be plotted against that originating from the normal channel, and the plot is analyzed. Or a ratio between the two intensities is obtained for each of one or more locations on the sample surface. Such operations may be performed by a processor 400 in Figs. 2A, 2B, 4, 5A, 5B.

[0042] As noted above in connection with Fig. 1C, a pit 32 of comparable size to a particle 24 will scatter a smaller amount of photon flux compared to particle 24 from an oblique beam 28'. Moreover, if the oblique incidence beam is P-polarized, the scattering caused by the particle is much stronger in directions at large angles to the normal direction to the surface compared to the scattering in directions close to the normal direction. This is not the case with a COP whose scattering pattern for an oblique incident P-polarized beam is more uniform in three-dimensional space. This feature can be exploited as illustrated in Fig. 11.

[0043] In reference to Figs. 2A and 11, the sample inspection system 500 of Fig. 11 differs from system 50 of Fig. 2A in that an additional detector 502 is employed with its corresponding pinhole 504. Direction 510 is normal to the surface 76a of the wafer 76. The radiation scattered in directions close to the normal direction 510 are reflected by a mirror 512 through the pinhole 504 to a photomultiplier tube 502 for detection. The radiation that is scattered by surface 76a in directions away from the normal direction 510 are collected by mirror 78 and focused to pinhole 80a and photomultiplier tube 80. Thus, detector 80 detects radiation scattered by surface 76a in directions at large angles to the normal direction 510 whereas detector 502 detects radiation scattered by the surface along directions close to the normal direction 510.

[0044] For the purpose of distinguished particles and COPs, the oblique illumination beam in the oblique channel 90 is preferably P-polarized. In such event, a particle on surface 76a illuminated by the oblique illumination beam will scatter radiation in a three-dimensional pattern similar to a toroid, which is relatively devoid of energy in a normal direction 510 and in directions close to the normal direction. A COP, on the other hand, would scatter such beam in a more uniform manner in three-dimensional space. Therefore, if the signal detected by detector 502 differs by a large factor from that detected by detector 80, the anomaly on surface 76a is more likely to be a particle, whereas if the signals detected by the two detectors differ by a smaller factor the anomaly present on surface 76a is more likely to be a COP.

[0045] The P-polarized oblique illumination beam in channel 90 may be provided by a laser 52 in the same manner as that described above in reference to Fig. 2A. The S-polarized beam reflected towards mirror 82 by polarizing beam splitter 62 may be altered into a P-polarized beam by a half-wave plate 84. Since the illumination beam in the normal channel is not used in system 500, it may simply be blocked (not shown in Fig. 11). A comparison of the outputs of the two detectors 80, 502 may be performed by a processor 400. Mirror 78 may be ellipsoidal in shape, or paraboloidal in shape (in which case an additional objective similar to objective 104 of Fig. 2B is also employed) or may have other suitable shapes.

[0046] While the invention has been described by reference to a normal and an oblique illumination beam, it will be understood that the normal illumination beam may be replaced by one that is not exactly normal to the surface, while retaining most of the advantages of the invention described above. Thus, such beam may be at a small angle to the normal direction, where the small angle is no more than 10° to the normal direction.

[0047] While the invention has been described above by reference to various embodiments, it will be understood that changes and modifications may be made without departing from the scope of the invention, which is to be defined only by the appended claims and their equivalents. For example, while only two illuminating beams or paths are shown in Figs. 2A, 2B, 4, 5A, 5B, it will be understood that three or more illuminating beams or paths may be employed and are within the scope of the invention.

Claims

1. An optical system (50; 100) for detecting anomalies of a sample, comprising:

   first means (60, 72, 74) for directing a first beam

(70) of radiation along a first path onto a first spot (70a) on a surface (76a) of the sample (76);
second means (60, 62, 82, 86) for directing a second beam (90) of radiation along a second path onto a second spot (90a) on a surface of the sample, said first and second paths being at different angles of incidence to said surface (76a) of the sample; and
a first detector (80);

characterised by:

means including a curved mirrored surface (78) configured to receive scattered radiation from the first or the second spot on the sample surface originating from the first or second beam, and to focus the scattered radiation to said first detector; and
in that said first detector is a non-imaging detector configured to provide an output in response to the total radiation focussed onto it by said curved mirrored surface.

2. The system of Claim 1, further comprising means (92) for causing relative motion between the two beams and the sample so that the spots are scanned across the surface of the sample.

3. The system of Claim 1 further comprising means (82) to change the direction of one of said beams in response to a detected change in sample height to compensate for the change in sample height to reduce beam position error caused thereby.

4. The system of any preceding claim, wherein said mirrored surface (78) is a curved surface and has an axis of symmetry substantially coaxial with the first path, defining an input aperture positioned proximate to the sample surface to receive scattered radiation therethrough from the sample surface.

5. The system of claim 4, said mirrored surface being a paraboloidal mirrored surface (78'), the mirrored surface reflecting radiation that passes through the input apeture, said receiving and focusing means further including means (104) for focusing radiation reflected by the mirrored surface to the first detector.

6. The system of claim 4, said mirrored surface being an ellipsoidal mirrored surface, the mirrored surface reflecting and focusing radiation that passes through the input aperture.

7. The system of any preceding claim, said first path being not more than about 10° angle from a normal direction to the sample surface.

8. The system of claim 7, said first path being substantially normal to the sample surface.

9. The system of claim 7, said second path being at an angle within a range of about 45 to 85 degrees to a normal direction to the sample surface.

10. The system of any one of claims 1 to 9, wherein said first and second spots substantially coincide.

11. The system of any one of claims 1 to 9, wherein first and second spots are separated by an offset (20).

12. The system of claim 11, said first or second beam having a point spread function with a spatial extent, wherein said offset is not less than said spatial extent but not greater than three times the spatial extent.

13. The system of any preceding claim, said first and second means comprising:

a source (52; 52') supplying a radiation beam; and
means (62; 162) for converting the radiation beam supplied by the source into said first and second beams.

14. The system of claim 13, said source supplying radiation of at least a first and a second wavelength, wherein said first detector (80(1)) detects radiation of the first wavelength, said system further comprising a second detector (80(2)) for detecting radiation of the second wavelength.

15. The system of claim 13, said converting means including a switch (182; 192) that causes the radiation beam from the source to be transmitted alternately along the two paths towards the sample surface.

16. The system of claim 15, said system further comprising means for acquiring data from the detector at a data rate, said switch operating at a frequency of at least about three times that of the data rate.

17. The system of claim 15, said system further comprising means for acquiring data from the detector at a data rate, said switch operating at a frequency of at least about five times that of the data rate.

18. The system of claim 15, said switch including an electro-optic modulator (182) or Bragg modulator (192).

19. The system of claim 1, 2 or 3 for detecting anomalies of a sample having a smooth surface, wherein

the second path is at an oblique angle to the sample surface, and the second beam is P or S polarised with respect to the sample surface.

20. The system of claim 1, 2 or 3, for detecting anomalies of a sample having a rough surface, wherein the second path is at an oblique angle to the sample surface, and the second beam is S polarised with respect to the sample surface.

21. The system of claim 1, 2 or 3 further comprising a spatial filter located at a position (300) between the curved mirrored surface (78) and the detector (80), the spatial filter blocking the scattered radiation towards the detector except for at least one area having wedge shape.

22. The system of claim 21 wherein the spatial filter comprises a liquid crystal spatial filter (350).

23. The system of claim 21 wherein the spatial filter has the shape of a butterfly with two wings where the wings are opaque to, or scatter, radiation and the spaces between the wings transmit radiation.

24. The system of any preceding claim, further comprising means (400) for comparing detected scattered radiation originating from the first beam and that originating from the second beam to distinguish between particles and COPs.

25. An optical method for detecting anomalies of a sample (76), comprising:

directing a first beam (70) of radiation along a first path onto a first spot (70a) on the surface (76a) of the sample; and
directing a second beam (90) of radiation along a second path onto a second spot (90a) on the surface of the sample, said first and second paths being at different angles of incidence to said surface of the sample; and

characterised by:

employing a curved mirrored surface (78) to receive scattered radiation from the first or second spot on the sample surface, originating from the first or second beam and focusing the scattered radiation to a first non-imaging detector (80); and
outputting a signal from said non-imaging detector in response to the total radiation focussed onto it by said curved mirrored surface.

26. The method of claim 25 further comprising causing relative motion between the two beams and the sample so that the spots are scanned across the surface of the sample.

27. The method of claim 25 or 26, said first path being not more than about 10° angle from a normal direction to the sample surface.

28. The method of claim 27, said first path being substantially normal to the sample surface.

29. The method of any one of claims 25 to 28, said second path being at an angle within a range of about 45 to 85 degrees to a normal direction to the sample surface.

30. The method of any one of claims 25 to 29 wherein said first and second spots substantially coincide.

31. The method of any one of claims 25 to 29 wherein said first and second spots are separated by an offset (120).

32. The method of claim 31, said first or second beam having a point spread function with a spatial extent, wherein said offset is not less than said spatial extent but not greater than three times the spatial extent.

33. The method of any one of claims 25 to 32, said first and second beam directing comprising:

providing a source (52, 52') supplying a radiation beam; and
converting the radiation beam supplied by the source into said first and second beams.

34. The method of claim 33, said source (52') supplying radiation of a first and a second wavelength, wherein said first detector (80(1)) detects radiation of the first wavelength, said method further comprising detecting radiation of the second wavelength by means of a second detector (80(2)).

35. The method of claim 33, said converting including switching the radiation beam from the source alternately between the two paths towards the sample surface.

36. The method of claim 35, said method further comprising acquiring data from the first detector at a data rate, wherein said switching is at a frequency of at least about three times that of the data rate.

37. The method of claim 35, said method further comprising acquiring data from the first detector at a data rate, wherein said switching is at a frequency of at least about five times that of the data rate.

38. The method of claim 25 or 26, for detecting anom-

alies of a sample having a smooth surface, wherein the second path is at an oblique angle to the sample surface, and the directing directs a second beam that is S or P polarized with respect to the sample surface.

39. The method of claim 25 or 26, for detecting anomalies of a sample having a rough surface, wherein the second path is at an oblique angle to the sample surface, and the directing directs a second beam that is S polarized with respect to the sample surface.

40. The method of claim 25 or 26, further comprising scanning sequentially the first and second beams across the same portion of the sample surface, wherein the first but not the second beam is directed to said surface while it is being scanned in a cycle, and the second but not the first beam is directed to said surface while it is being scanned in a subsequent cycle.

41. The method of any one of claims 25 to 40, further comprising comparing detected scattered radiation originating from the first beam and that originating from the second beam to distinguish between particles and COPs.

Patentansprüche

1. Optisches System (50; 100) zum Erfassen von Abnormalitäten einer Probe, umfassend:

eine erste Einrichtung (60, 72, 74) zum Richten eines ersten Strahls (70) einer Strahlung entlang eines ersten Pfads auf einem ersten Fleck (70a) auf einer Oberfläche (76a) der Probe (76);
eine zweite Einrichtung (60, 62, 82, 86) zum Richten eines zweiten Strahls (90) einer Strahlung entlang eines zweiten Pfads auf einen zweiten Fleck (90a) auf einer Oberfläche der Probe, wobei die ersten und zweiten Pfade bei unterschiedlichen Einfallswinkeln zu der Oberfläche (76a) der Probe sind; und
einen ersten Detektor (80);

gekennzeichnet durch:

eine Einrichtung mit einer gekrümmten gespiegelten Oberfläche (78), die konfiguriert ist, um eine gestreute Strahlung von dem ersten oder dem zweiten Fleck auf der Probenoberfläche, die von dem ersten oder zweiten Strahl herrührt, zu empfangen und die gestreute Strahlung an den ersten Detektor zu fokussieren; und
dass der erste Detektor ein nicht-abbildender Detektor ist, der konfiguriert ist, um einen Ausgang im Ansprechen auf die Gesamtstrahlung, die darauf **durch** die gekrümmte gespiegelte Oberfläche fokussiert wird, bereitzustellen.

2. System nach Anspruch 1, ferner umfassend eine Einrichtung (92), um eine relative Bewegung zwischen den zwei Strahlen und der Probe zu verursachen, so dass die Flecken über der Oberfläche der Probe gescannt werden.

3. System nach Anspruch 1, ferner umfassend eine Einrichtung (82) zum Ändern der Richtung von einem der Strahlen im Ansprechen auf eine erfasste Änderung in der Probenhöhe, um eine Kompensation für die Änderung in der Probenhöhe bereitzustellen, um einen dadurch verursachten Strahlpositionsfehler zu verringern.

4. System nach irgendeinem vorangehenden Anspruch, wobei die gespiegelte Oberfläche (78) eine gekrümmte Oberfläche ist und eine Symmetrieachse im wesentlichen koaxial zu dem ersten Pfad aufweist, wobei eine Eingangsöffnung definiert wird, die in der Nähe zu der Probenoberfläche positioniert ist, um dadurch von der Probenoberfläche eine gestreute Strahlung zu empfangen.

5. System nach Anspruch 4, wobei die gespiegelte Oberfläche eine paraboloid-förmige gespiegelte Oberfläche (87') ist, wobei die gespiegelte Oberfläche eine Strahlung reflektiert, die durch die Eingangsöffnung tritt, wobei die Empfangs- und Fokussierungseinrichtung ferner eine Einrichtung (104) zum Fokussieren von Strahlung, die von der gespiegelten Oberfläche an den ersten Detektor reflektiert wird, einschließt.

6. System nach Anspruch 4, wobei die gespiegelte Oberfläche eine ellipsoid-förmige gespiegelte Oberfläche ist, wobei die gespiegelte Oberfläche eine Strahlung, die durch die Eingangsöffnung tritt, reflektiert und fokussiert.

7. System nach irgendeinem vorangehenden Anspruch, wobei der erste Pfad nicht mehr als ungefähr ein 10°-Winkel von einer normalen Richtung zu der Probenoberfläche ist.

8. System nach Anspruch 7, wobei der erste Pfad im wesentlichen normal zu der Probenoberfläche ist.

9. System nach Anspruch 7, wobei der zweite Pfad bei einem Winkel innerhalb eines Bereichs von ungefähr 45 bis 85 Grad zu einer normalen Richtung zu der Probenoberfläche ist.

10. System nach irgendeinem der Ansprüche 1 bis 9, wobei die ersten und zweiten Flecken im wesentlichen übereinstimmen.

11. System nach irgendeinem der Ansprüche 1 bis 9, wobei erste und zweite Flecken durch einen Versatz (20) getrennt sind.

12. System nach Anspruch 11, wobei der erste oder zweite Strahl eine Punktspreizungsfunktion mit einer räumlichen Ausdehnung aufweist, wobei der Versatz nicht kleiner als die räumliche Ausdehnung, aber nicht größer als drei mal die räumliche Ausdehnung ist.

13. System nach irgendeinem voranstehenden Anspruch, wobei die ersten und zweiten Einrichtungen umfassen:

eine Quelle (52; 52'), die einen Strahlungsstrahl zuführt; und
eine Einrichtung (62; 162) zum Umwandeln des Strahlungsstrahls, der von der Quelle zugeführt wird, in die ersten und zweiten Strahlen.

14. System nach Anspruch 13, wobei die Quelle eine Strahlung von wenigstens einer ersten und zweiten Wellenlänge zuführt, wobei der erste Detektor (80 (1)) eine Strahlung der ersten Wellenlänge erfasst, wobei das System ferner einen zweiten Detektor (80(2)) zum Erfassen einer Strahlung der zweiten Wellenlänge umfasst.

15. System nach Anspruch 13, wobei die Umwandlungseinrichtung einen Schalter (182; 192) einschließt, der bewirkt, dass der Strahlungsstrahl von der Quelle abwechselnd entlang der zwei Pfade in Richtung auf die Probenoberfläche hin übertragen wird.

16. System nach Anspruch 15, wobei das System ferner eine Einrichtung zum Sammeln von Daten von dem Detektor bei einer Datenrate umfasst, wobei der Schalter bei einer Frequenz von wenigstens ungefähr drei mal von derjenigen der Datenrate arbeitet.

17. System nach Anspruch 15, wobei das System ferner eine Einrichtung zum Sammeln von Daten von dem Detektor bei einer Datenrate umfasst, wobei der Schalter bei einer Frequenz von wenigstens ungefähr fünf mal von derjenigen der Datenrate arbeitet.

18. System nach Anspruch 15, wobei der Schalter einen elektro-optischen Modulator (182) oder einen Bragg-Modulator (192) einschließt.

19. System nach Anspruch 1, 2 oder 3 zum Erfassen von Abnormalitäten einer Probe mit einer glatten Oberfläche, wobei der zweite Pfad bei einem schrägen Winkel zu der Probenoberfläche ist und der zweite Strahl in Bezug auf die Probenoberfläche P oder S polarisiert ist.

20. System nach Anspruch 1, 2 oder 3 zum Erfassen von Abnormalitäten einer Probe mit einer rauen Oberfläche, wobei der zweite Pfad bei einem schrägen Winkel zu der Probenoberfläche ist, und der zweite Strahl in Bezug auf die Probenoberfläche S polarisiert ist.

21. System nach Anspruch 1, 2 oder 3, ferner umfassend ein räumliches Filter, das an einer Position (300) zwischen der gekrümmten gespiegelten Oberfläche (78) und dem Detektor (80) angeordnet ist, wobei das räumliche Filter die gestreute Strahlung in Richtung auf den Detektor hin mit Ausnahme von wenigstens einem Gebiet mit einer Keilform abblockt.

22. System nach Anspruch 21, wobei das räumliche Filter ein räumliches Flüssigkristall-Filter (350) umfasst.

23. System nach Anspruch 21, wobei das räumliche Filter die Form eines Schmetterlings mit zwei Flügeln aufweist, wobei die Flügel lichtundurchlässig für eine Strahlung sind oder diese streuen und die Räume zwischen den Flügeln eine Strahlung übertragen.

24. System nach irgendeinem vorangehenden Anspruch, ferner umfassend eine Einrichtung (400) zum Vergleichen einer erfassten gestreuten Strahlung, die von dem ersten Strahl henührt und derjenigen, die von dem zweiten Strahl herrührt, um zwischen Partikeln und COPs zu unterscheiden.

25. Optisches Verfahren zum Erfassen von Abnormalitäten einer Probe (76), umfassend:

Richten eines ersten Strahls (70) einer Strahlung entlang eines ersten Pfads auf einen ersten Fleck (70a) auf der Oberfläche (76a) der Probe; und

Richten eines zweiten Strahls (90) einer Strahlung entlang eines zweiten Pfads auf einen zweiten Fleck (90a) auf der Oberfläche der Probe, wobei die ersten und zweiten Pfade bei unterschiedlichen Einfallswinkeln zu der Oberfläche der Probe sind; und

gekennzeichnet durch die folgenden Schritte:

Verwenden einer gekrümmten gespiegelten Oberfläche (78), um eine gestreute Strahlung von dem ersten oder zweiten Fleck auf der Probenoberfläche zu empfangen, die von dem ersten oder zweiten Strahl herrührt, und Fokussieren der gestreuten Strahlung auf einen ersten nicht-abbildenden Detektor (80); und Ausgeben eines Signals von dem nicht-abbildenden Detektor im Ansprechen auf die gesamte Strahlung, die **durch** die gekrümmte gespiegelte Oberfläche darauf fokussiert wird.

26. Verfahren nach Anspruch 25, ferner umfassend den Schritt, bei dem eine relative Bewegung zwischen den zwei Strahlen und der Probe verursacht wird, so dass die Flecke über die Oberfläche der Probe gescannt worden.

27. Verfahren nach Anspruch 25 oder 26, wobei der erste Pfad nicht mehr als ungefähr ein 10°-Winkel von einer normalen Richtung zu der Probenoberfläche ist.

28. Verfahren nach Anspruch 27, wobei der erste Pfad im wesentlichen normal zu der Probenoberfläche ist.

29. Verfahren nach irgendeinem der Ansprüche 25 bis 28, wobei der zweite Pfad bei einem Winkel innerhalb eines Bereichs von ungefähr 45 bis 85 Grad zu einer normalen Richtung zu der Probenoberfläche ist.

30. Verfahren nach irgendeinem der Ansprüche 25 bis 29, wobei die ersten und zweiten Flecken im wesentlichen übereinstimmen.

31. Verfahren nach irgendeinem der Ansprüche 25 bis 29, wobei die ersten und zweiten Flecken durch einen Versatz (120) getrennt sind.

32. Verfahren nach Anspruch 31, wobei der erste oder zweite Stahl eine Punktspreizungsfunktion mit einer räumlichen Ausdehnung aufweist, wobei der Versatz nicht kleiner als die räumliche Ausdehnung, aber nicht größer als drei mal die räumliche Ausdehnung ist.

33. Verfahren nach irgendeinem der Ansprüche 25 bis 32, wobei das Richten des ersten und zweiten Strahls umfasst:

Bereitstellen einer Quelle (52, 52'), die einen Strahlungsstrahl zuführt; und

Umwandeln des Strahlungsstrahls, der von der Quelle zugeführt wird, in die ersten und zweiten Strahlen.

34. Verfahren nach Anspruch 33, wobei die Quelle (25') eine Strahlung mit einer ersten und einer zweiten Wellenlänge zuführt, wobei der erste Detektor (80 (1)) eine Strahlung der ersten Wellenlänge erfasst, wobei das Verfahren ferner das Erfassen einer Strahlung der zweiten Wellenlänge mit Hilfe eines zweiten Detektors (80(2)) umfasst.

35. Verfahren nach Anspruch 33, wobei das Umwandeln ein Umschalten des Strahlungsstrahls von der Quelle abwechselnd zwischen den zwei Pfaden auf die Probenoberfläche hin einschließt.

36. Verfahren nach Anspruch 35, wobei das Verfahren ferner ein Sammeln von Daten von dem ersten Detektor bei einer Datenrate umfasst, wobei das Umschalten bei einer Frequenz von wenigstens ungefähr drei mal der Datenrate stattfindet.

37. Verfahren nach Anspruch 35, wobei das Verfahren ferner das Sammeln von Daten von dem ersten Detektor bei einer Datenrate umfasst, wobei das Umschalten bei einer Frequenz von wenigstens ungefähr fünf mal von derjenigen der Datenraten stattfindet.

38. Verfahren nach Anspruch 25 oder 26, zum Erfassen von Abnormalitäten einer Probe mit einer glatten Oberfläche, wobei der zweite Pfad bei einem schrägen Winkel zu der Probenoberfläche ist, und das Richten einen zweiten Strahl richtet, der in Bezug auf die Probenoberfläche S oder P polarisiert ist.

39. Verfahren nach Anspruch 25 oder 26, zum Erfassen von Abnormalitäten einer Probe mit einer rauen Oberfläche, wobei der zweite Pfad bei einem schrägen Winkel zu der Probenoberfläche ist und das Richten einen zweiten Strahl richtet, der in Bezug auf die Probenoberfläche S polarisiert ist.

40. Verfahren nach Anspruch 25 oder 26, ferner umfassend ein sequenzielles Scannen der ersten und zweiten Strahlen über den gleichen Abschnitt der Probenoberfläche, wobei der erste, aber nicht der zweite Strahl, auf die Oberfläche gerichtet wird, während er gerade in einem Zyklus gescannt wird und der zweite, aber nicht der erste Strahl, auf die Oberfläche gerichtet wird, während er gerade in einem nachfolgenden Zyklus gescannt wird.

41. Verfahren nach irgendeinem der Ansprüche 25 bis 40, ferner umfassend ein Vergleichen einer erfassten gestreuten Strahlung, die von dem ersten Strahl herrührt und derjenigen, die von dem zweiten Strahl herrührt, um zwischen Partikeln und COPs zu unterscheiden.

Revendications

1. Système optique (50; 100) pour détecter des anomalies d'un échantillon, comprenant :

   un premier moyen (60, 72, 74) pour diriger un premier faisceau (70) de rayonnement suivant une première voie selon un premier spot (70a) sur une surface (76a) de l'échantillon (76);
   un second moyen (60, 62, 82, 86) pour diriger un second faisceau (90) de rayonnement suivant une seconde voie selon un second spot (90a) sur une surface de l'échantillon, lesdites première et seconde voies étant selon des angles d'incidence différents par rapport à ladite surface (76a) de l'échantillon; et
   un premier détecteur (80);

   caractérisé par:

   un moyen incluant une surface miroir incurvée (78) qui est configurée pour recevoir un rayonnement diffusé depuis le premier ou le second spot sur la surface d'échantillon, qui prend son origine depuis le premier ou le second faisceau, et pour focaliser le rayonnement diffusé sur ledit premier détecteur; et en ce que
   ledit premier détecteur est un détecteur non imageur qui est configuré pour produire une sortie en réponse au rayonnement total focalisé sur lui par ladite surface miroir incurvée.

2. Système selon la revendication 1, comprenant en outre un moyen (92) pour provoquer un déplacement relatif entre les deux faisceaux et l'échantillon de telle sorte que les spots soient balayés sur la surface de l'échantillon.

3. Système selon la revendication 1, comprenant en outre un moyen (82) pour changer la direction de l'un desdits faisceaux en réponse à une variation détectée de la hauteur d'échantillon afin de compenser la variation de hauteur d'échantillon afin de réduire une erreur de position de faisceau provoquée par le système.

4. Système selon l'une quelconque des revendications précédentes, dans lequel ladite surface miroir (78) est une surface incurvée et présente un axe de symétrie sensiblement coaxial avec la première voie, définissant une ouverture d'entrée positionnée à proximité de la surface d'échantillon afin de recevoir un rayonnement diffusé au travers depuis la surface d'échantillon.

5. Système selon la revendication 4, dans lequel ladite surface miroir est une surface miroir parabolique (78'), la surface miroir réfléchit le rayonnement qui passe au travers de l'ouverture d'entrée et ledit moyen de réception et de focalisation inclut en outre un moyen (104) pour focaliser un rayonnement réfléchi par la surface miroir sur le premier détecteur.

6. Système selon la revendication 4, dans lequel ladite surface miroir est une surface miroir ellipsoïdale et la surface miroir réfléchit et focalise le rayonnement qui passe au travers de l'ouverture d'entrée.

7. Système selon l'une quelconque des revendications précédentes, dans lequel ladite première voie est selon un angle pas plus grand qu'environ 10° par rapport à une direction normale à la surface d'échantillon.

8. Système selon la revendication 7, dans lequel ladite première voie est sensiblement normale à la surface d'échantillon.

9. Système selon la revendication 7, dans lequel ladite seconde voie est selon un angle dans une plage d'environ 45 à 85 degrés par rapport à une direction normale à la surface d'échantillon.

10. Système selon l'une quelconque des revendications 1 à 9, dans lequel lesdits premier et second spots sont sensiblement en coïncidence.

11. Système selon l'une quelconque des revendications 1 à 9, dans lequel lesdits premier et second spots sont séparés par un décalage (20).

12. Système selon la revendication 11, dans lequel lesdits premier et second faisceaux présentent une fonction d'étalement de point avec une extension spatiale, ledit décalage n'étant pas inférieur à ladite extension spatiale mais pas supérieur à trois fois l'extension spatiale.

13. Système selon l'une quelconque des revendications précédentes, dans lequel lesdits premier et second moyens comprennent:

    une source (52; 52') produisant un faisceau de rayonnement; et
    un moyen (62; 162) pour convertir le faisceau de rayonnement produit par la source selon lesdits premier et second faisceaux.

14. Système selon la revendication 13, dans lequel ladite source produit le rayonnement d'au moins une première et une seconde longueurs d'onde, ledit premier détecteur (80(1)) détecte un rayonnement de la première longueur d'onde et ledit système comprend en outre un second détecteur (80(2)) pour détecter un rayonnement de la seconde longueur d'onde.

15. Système selon la revendication 13, dans lequel ledit moyen de conversion inclut un commutateur (182; 192) qui fait en sorte que le faisceau de rayonnement depuis la source est transmis alternativement suivant les deux voies vers la surface d'échantillon.

16. Système selon la revendication 15, dans lequel ledit système comprend en outre un moyen pour acquérir des données depuis le détecteur selon un débit de données, ledit commutateur fonctionnant à une fréquence d'au moins environ trois fois le débit de données.

17. Système selon la revendication 15, dans lequel ledit système comprend en outre un moyen pour acquérir des données depuis le détecteur selon un débit de données, ledit commutateur fonctionnant à une fréquence d'au moins environ cinq fois le débit de données.

18. Système selon la revendication 15, dans lequel ledit commutateur inclut un modulateur électro-optique (182) ou un modulateur de Bragg (192).

19. Système selon l'une quelconque des revendications 1, 2 ou 3 pour détecter des anomalies d'un échantillon présentant une surface lisse, dans lequel la seconde voie est selon un angle oblique par rapport à la surface d'échantillon et le second faisceau est polarisé P ou S par rapport à la surface d'échantillon.

20. Système selon l'une quelconque des revendications 1, 2 ou 3 pour détecter des anomalies d'un échantillon présentant une surface rugueuse, dans lequel la seconde voie est selon un angle oblique par rapport à la surface d'échantillon et le second faisceau est polarisé S par rapport à la surface d'échantillon.

21. Système selon l'une quelconque des revendications 1, 2 ou 3, comprenant en outre un filtre spatial situé en une position (300) entre la surface miroir incurvée (78) et le détecteur (80), le filtre spatial bloquant un rayonnement diffusé vers le détecteur à l'exception d'au moins une aire présentant une forme de coin.

22. Système selon la revendication 21, dans lequel le filtre spatial comprend un filtre spatial à cristaux liquides (350).

23. Système selon la revendication 21, dans lequel le filtre spatial présente la forme d'un papillon avec deux ailes, les ailes étant opaques ou diffusantes par rapport au rayonnement et les espaces entre les ailes transmettant le rayonnement.

24. Système selon l'une quelconque des revendications précédentes, comprenant en outre un moyen (400) pour comparer un rayonnement diffusé détecté ayant son origine depuis le premier faisceau par rapport à celui ayant son origine depuis le second faisceau afin de distinguer entre des particules et des COP.

25. Procédé optique pour détecter des anomalies d'un échantillon (76), comprenant:

la direction d'un premier faisceau (70) de rayonnement suivant une première voie selon un premier spot (70a) sur une surface (76a) de l'échantillon; et
la direction d'un second faisceau (90) de rayonnement suivant une seconde voie selon un second spot (90a) sur une surface de l'échantillon, lesdites première et seconde voies étant selon des angles d'incidence différents par rapport à ladite surface de l'échantillon; et

caractérisé par:

l'emploi d'une surface miroir incurvée (78) pour recevoir un rayonnement diffusé depuis le premier ou le second spot sur la surface d'échantillon, qui prend son origine depuis le premier ou le second faisceau, et pour focaliser le rayonnement diffusé sur ledit premier détecteur non imageur (80); et
la sortie d'un signal depuis un détecteur non imageur en réponse au rayonnement total focalisé sur lui par ladite surface miroir incurvée.

26. Procédé selon la revendication 25, comprenant en outre une action pour provoquer un déplacement relatif entre les deux faisceaux et l'échantillon de telle sorte que les spots soient balayés sur la surface de l'échantillon.

27. Procédé selon la revendication 25 ou 26, dans lequel ladite première voie est selon un angle pas plus grand qu'environ 10° par rapport à une direction normale à la surface d'échantillon.

28. Procédé selon la revendication 27, dans lequel ladite première voie est sensiblement normale à la surface d'échantillon.

29. Procédé selon l'une quelconque des revendications 25 à 28, dans lequel ladite seconde voie est selon un angle dans une plage d'environ 45 à 85 degrés par rapport à une direction normale à la surface d'échantillon.

30. Procédé selon l'une quelconque des revendications 25 à 29, dans lequel lesdits premier et second spots sont sensiblement en coïncidence.

31. Procédé selon l'une quelconque des revendications 25 à 29, dans lequel lesdits premier et second spots sont séparés par un décalage (120).

32. Procédé selon la revendication 31, dans lequel lesdits premier et second faisceaux présentent une fonction d'étalement de point avec une extension spatiale, ledit décalage n'étant pas inférieur à ladite extension spatiale mais pas supérieur à trois fois l'extension spatiale.

33. Procédé selon l'une quelconque des revendications 25 à 32, dans lequel lesdits premier et second moyens de direction de faisceau comprennent:

    la fourniture d'une source (52; 52') produisant un faisceau de rayonnement; et
    la conversion du faisceau de rayonnement produit par la source selon lesdits premier et second faisceaux.

34. Procédé selon la revendication 33, dans lequel ladite source (52') produit le rayonnement d'une première et une seconde longueurs d'onde, ledit premier détecteur (80(1)) détecte un rayonnement de la première longueur d'onde et ledit procédé comprend en outre la détection d'un rayonnement de la seconde longueur d'onde au moyen d'un second détecteur (80(2)).

35. Procédé selon la revendication 33, dans lequel ladite conversion inclut une commutation du faisceau de rayonnement depuis la source alternativement suivant les deux voies vers la surface d'échantillon.

36. Procédé selon la revendication 35, comprenant en outre l'acquisition des données depuis le premier détecteur selon un débit de données, ledit commutateur fonctionnant à une fréquence d'au moins environ trois fois le débit de données.

37. Procédé selon la revendication 35, comprenant en outre l'acquisition des données depuis le premier détecteur selon un débit de données, ledit commutateur fonctionnant à une fréquence d'au moins environ cinq fois le débit de données.

38. Système selon la revendication 25 ou 26 pour détecter des anomalies d'un échantillon présentant une surface lisse, dans lequel la seconde voie est selon un angle oblique par rapport à la surface d'échantillon et la direction dirige un second faisceau qui est polarisé P ou S par rapport à la surface d'échantillon.

39. Procédé selon la revendication 25 ou 26 pour détecter des anomalies d'un échantillon présentant une surface rugueuse, dans lequel la seconde voie est selon un angle oblique par rapport à la surface d'échantillon et la direction dirige un second faisceau qui est polarisé S par rapport à la surface d'échantillon.

40. Procédé selon la revendication 25 ou 26, comprenant en outre le balayage séquentiel les premier et second faisceaux sur la même partie de la surface d'échantillon, dans lequel le premier mais pas le second faisceau est dirigé sur ladite surface tandis qu'il est balayé selon un cycle et le second mais pas le premier faisceau est dirigé sur ladite surface tandis qu'il est balayé selon un cycle suivant.

41. Procédé selon l'une quelconque des revendications 25 à 40, comprenant en outre la comparaison du rayonnement diffusé détecté ayant son origine depuis le premier faisceau par rapport à celui ayant son origine depuis le second faisceau afin d'effectuer une distinction entre des particules et des COP.

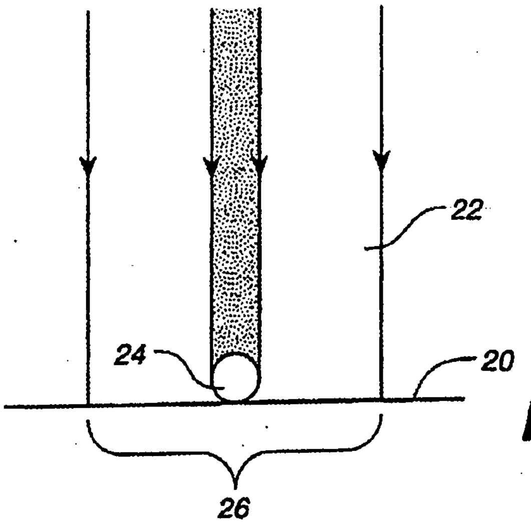

FIG._1A

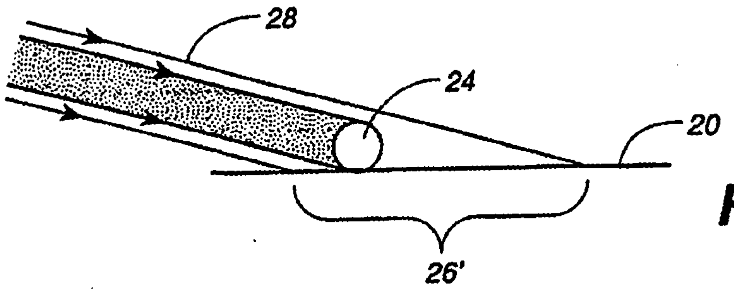

FIG._1B

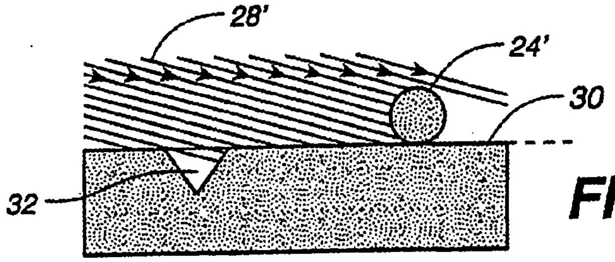

FIG._1C

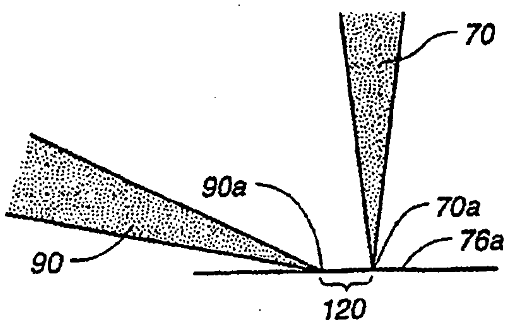
70
90a
70a
76a
90
120

FIG._3

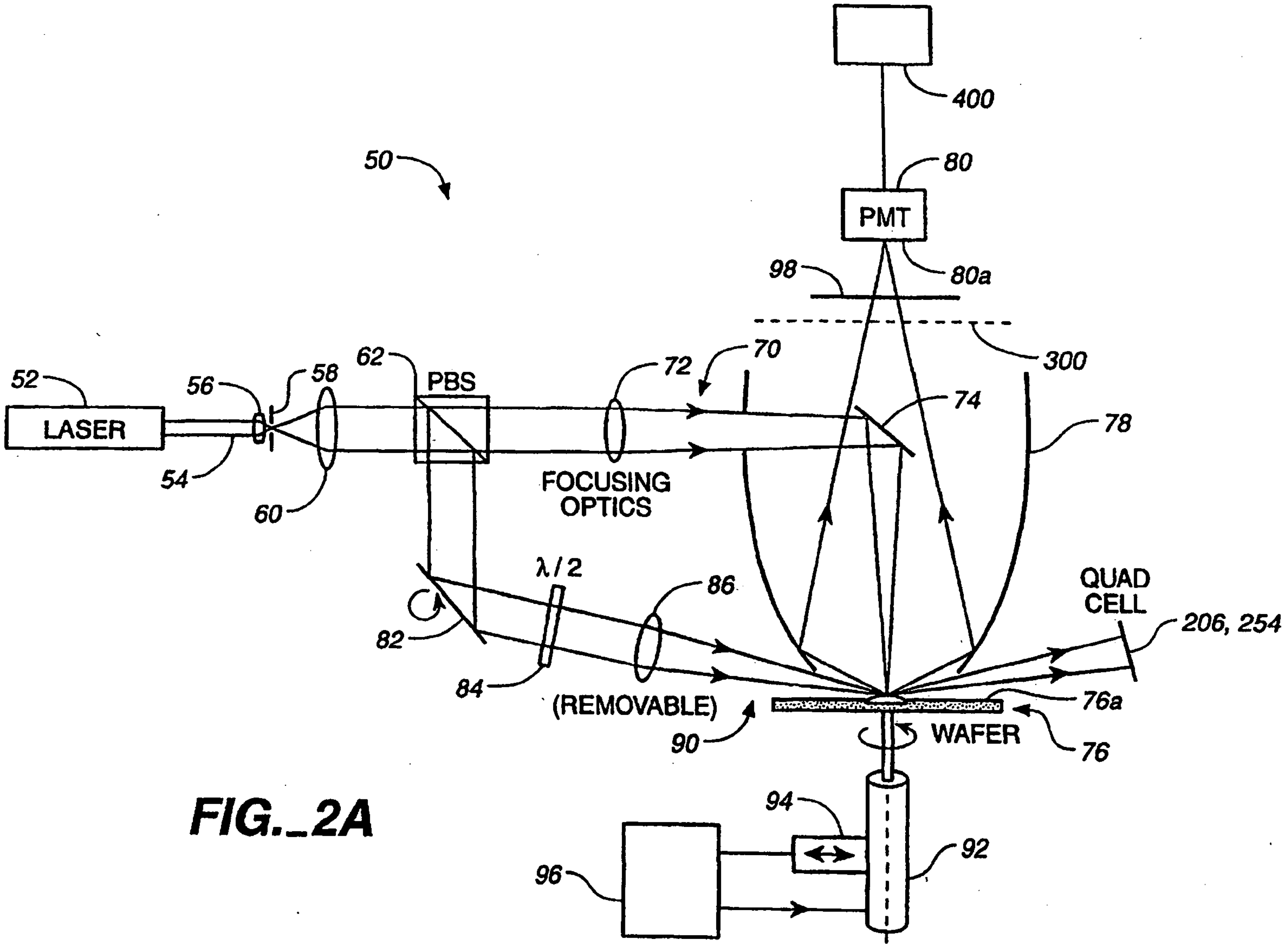
PMT
LASER
PBS
FOCUSING
OPTICS
λ/2
(REMOVABLE)
QUAD
CELL
206, 254
WAFER

FIG._2A

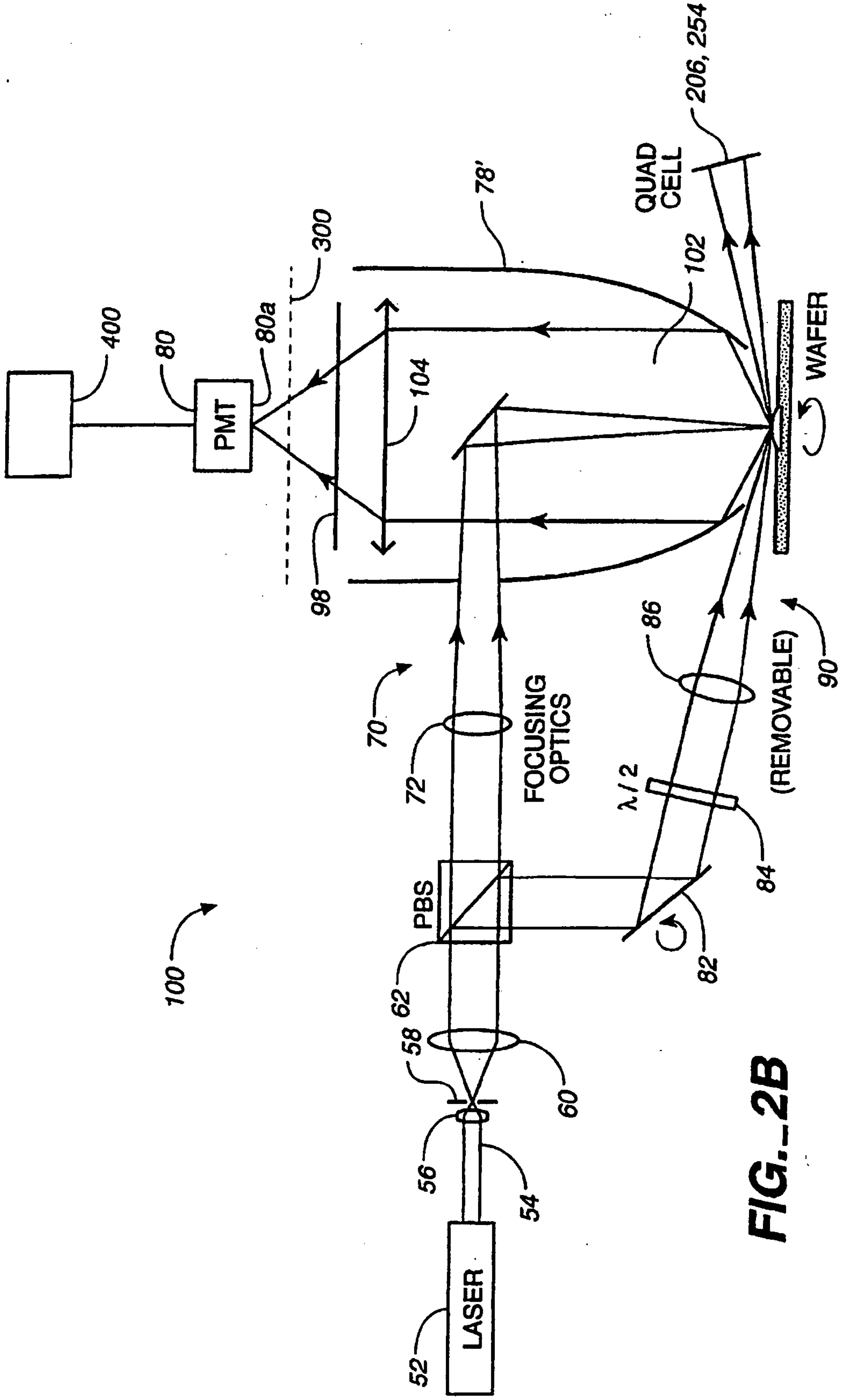
LASER
PBS
λ/2
(REMOVABLE)
FOCUSING OPTICS
PMT
QUAD CELL
206, 254
WAFER

FIG._2B

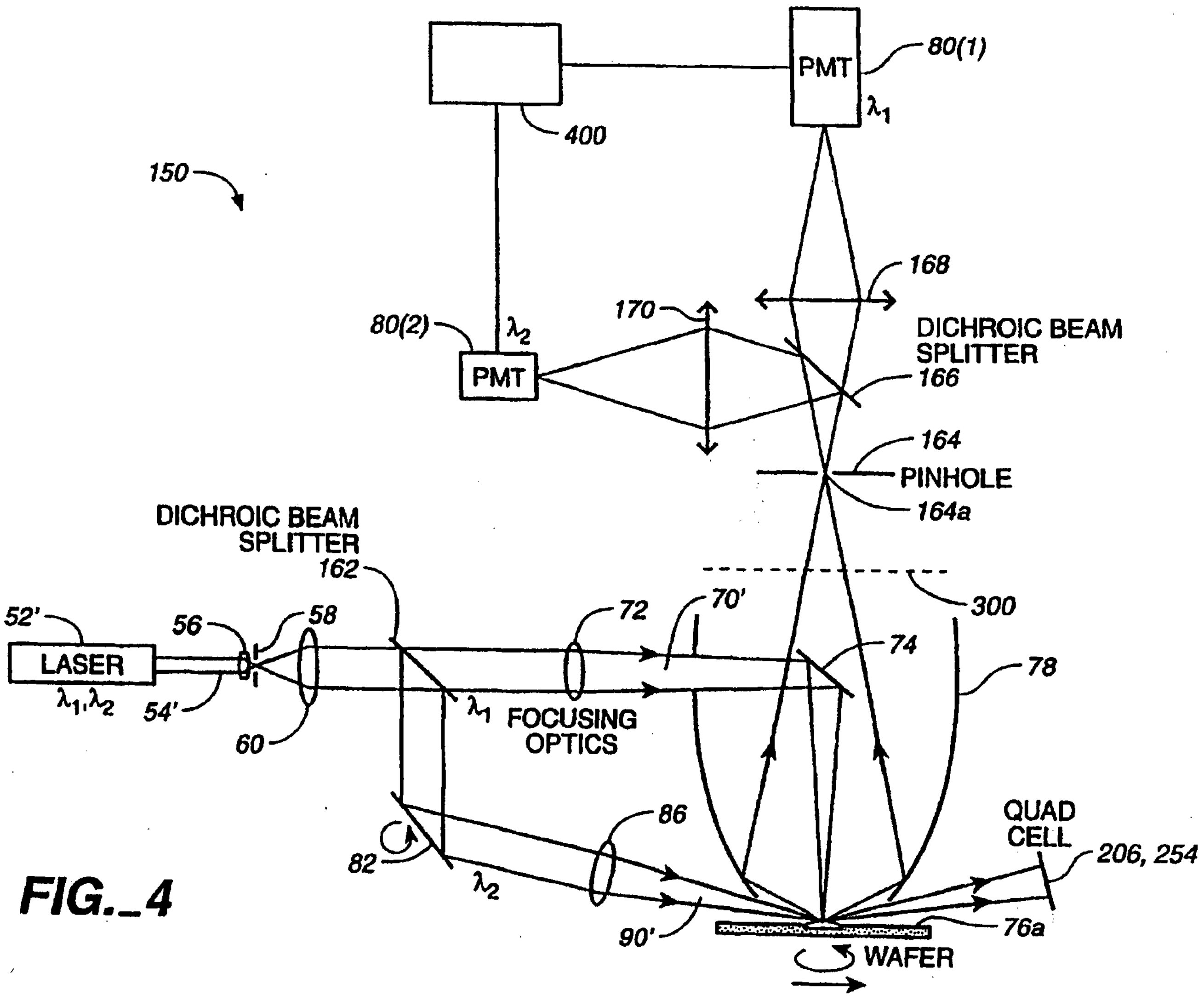
PMT
λ1
λ2
PMT
DICHROIC BEAM SPLITTER
PINHOLE
DICHROIC BEAM SPLITTER
LASER
λ1,λ2
λ1
FOCUSING OPTICS
λ2
QUAD CELL
206, 254
WAFER

FIG._4

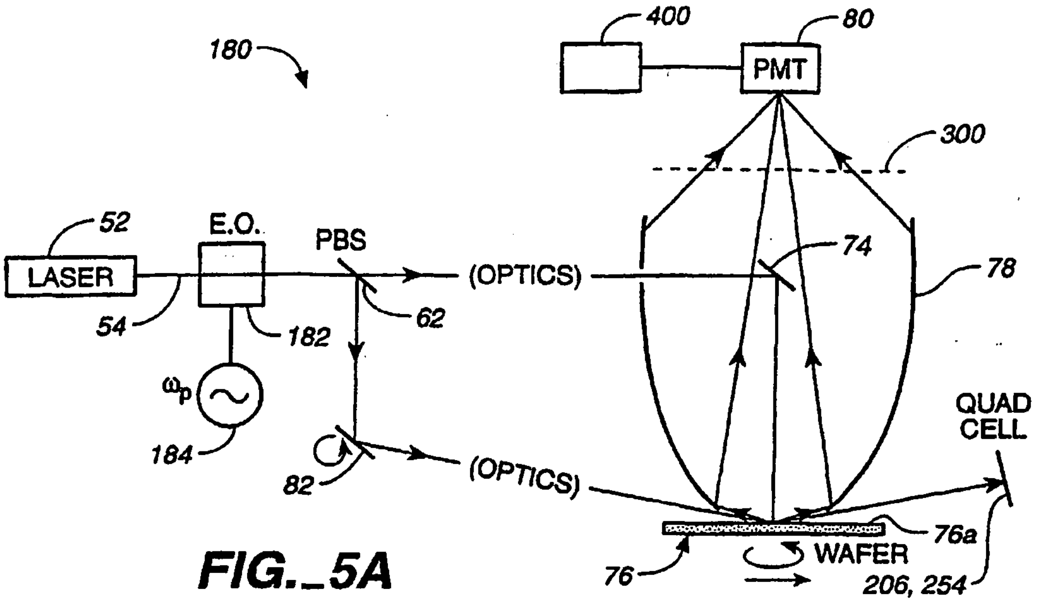
180
400
80
PMT
300
52
E.O.
PBS
LASER
(OPTICS)
74
78
54
182
62
ωp
184
82
(OPTICS)
QUAD CELL
76a
WAFER
76
206, 254

FIG._5A

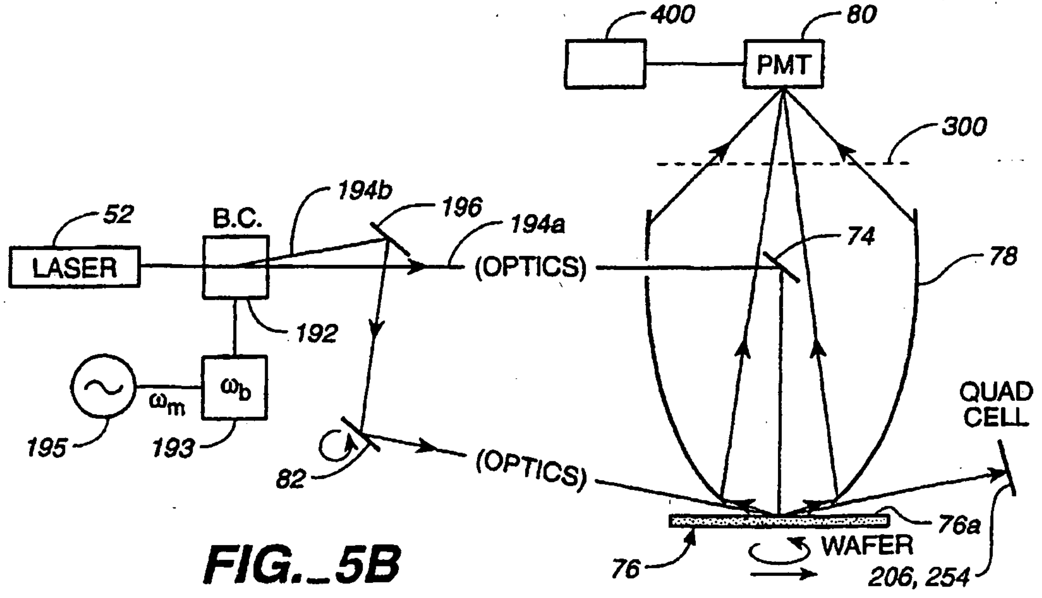
PMT
B.C.
LASER
(OPTICS)
ωb
ωm
(OPTICS)
QUAD CELL
WAFER
206, 254

FIG._5B

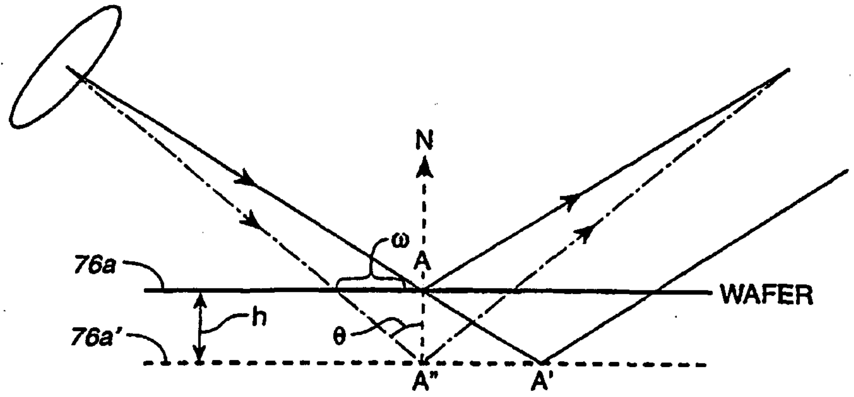
N
ω
A
76a
WAFER
h
76a'
θ
A"
A'

FIG._6

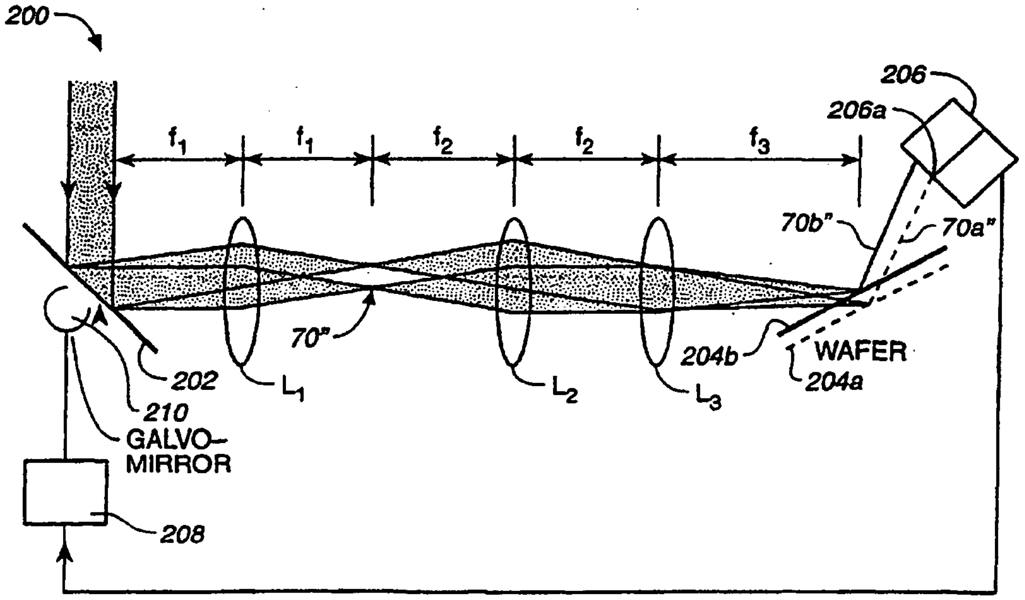
200
206
206a
f1
f1
f2
f2
f3
70b"
70a"
70"
204b
WAFER
204a
202
L1
L2
L3
210
GALVO-
MIRROR
208

FIG._7

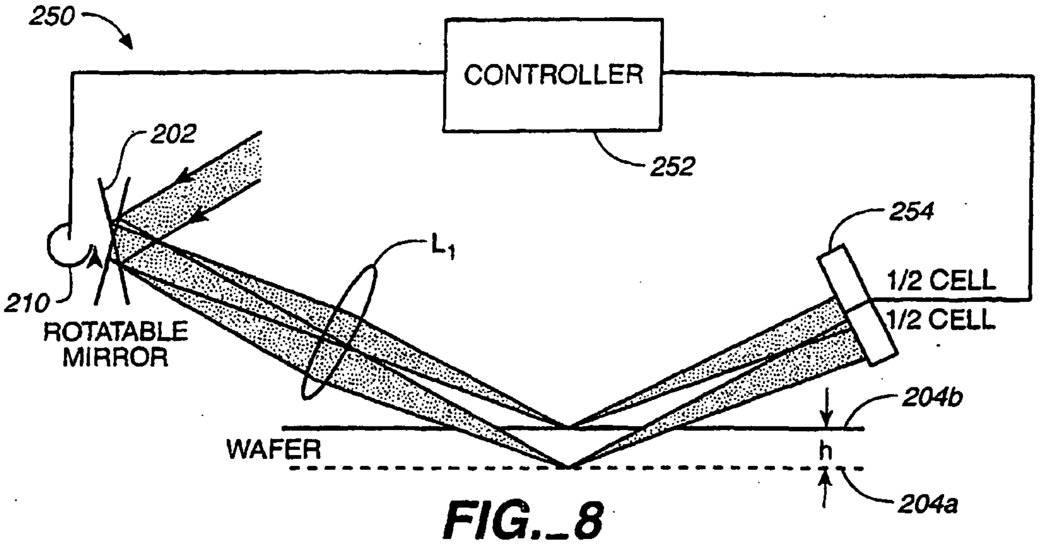
250
CONTROLLER
252
202
254
L1
210
ROTATABLE MIRROR
1/2 CELL
1/2 CELL
204b
WAFER
h
204a

FIG._8

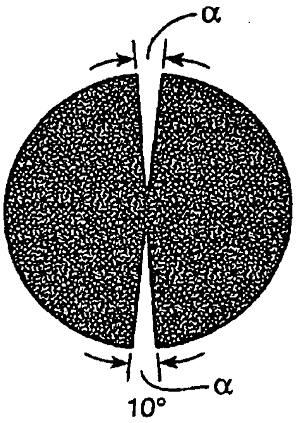

FIG._9A

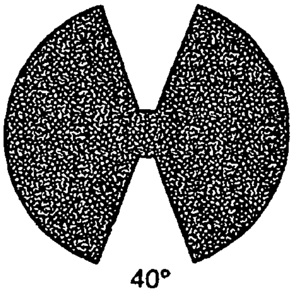

FIG._9C

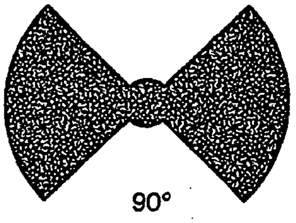

FIG._9E

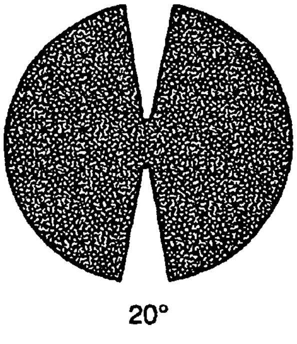

FIG._9B

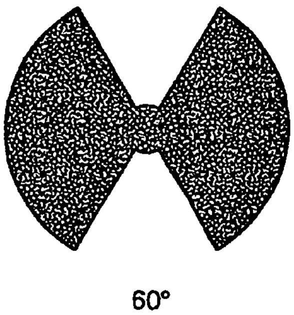

FIG._9D

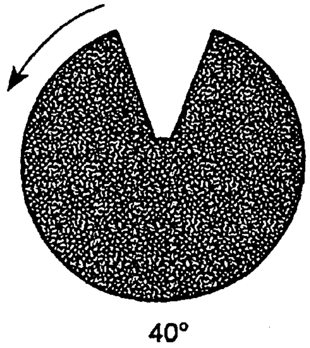

FIG._9F

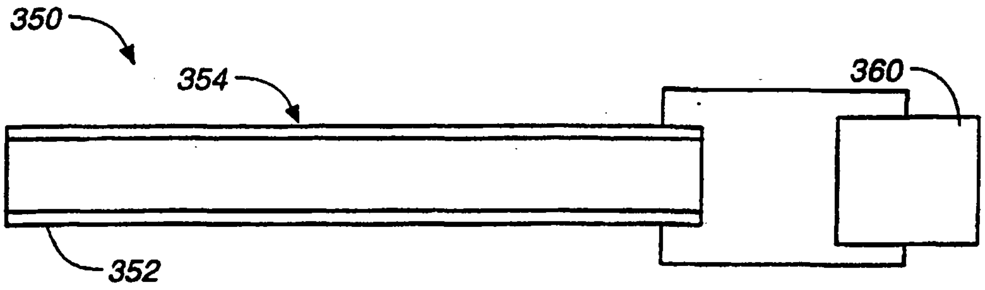
350
354
360
352

FIG._10A

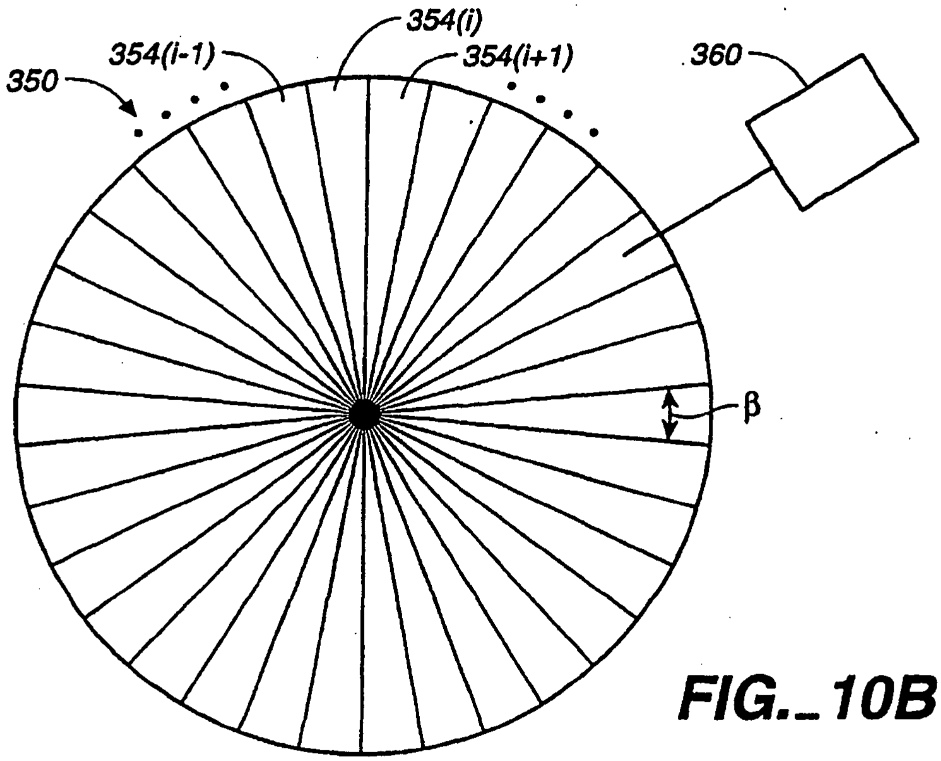
354(i)
354(i-1)
354(i+1)
350
360
β

FIG._10B

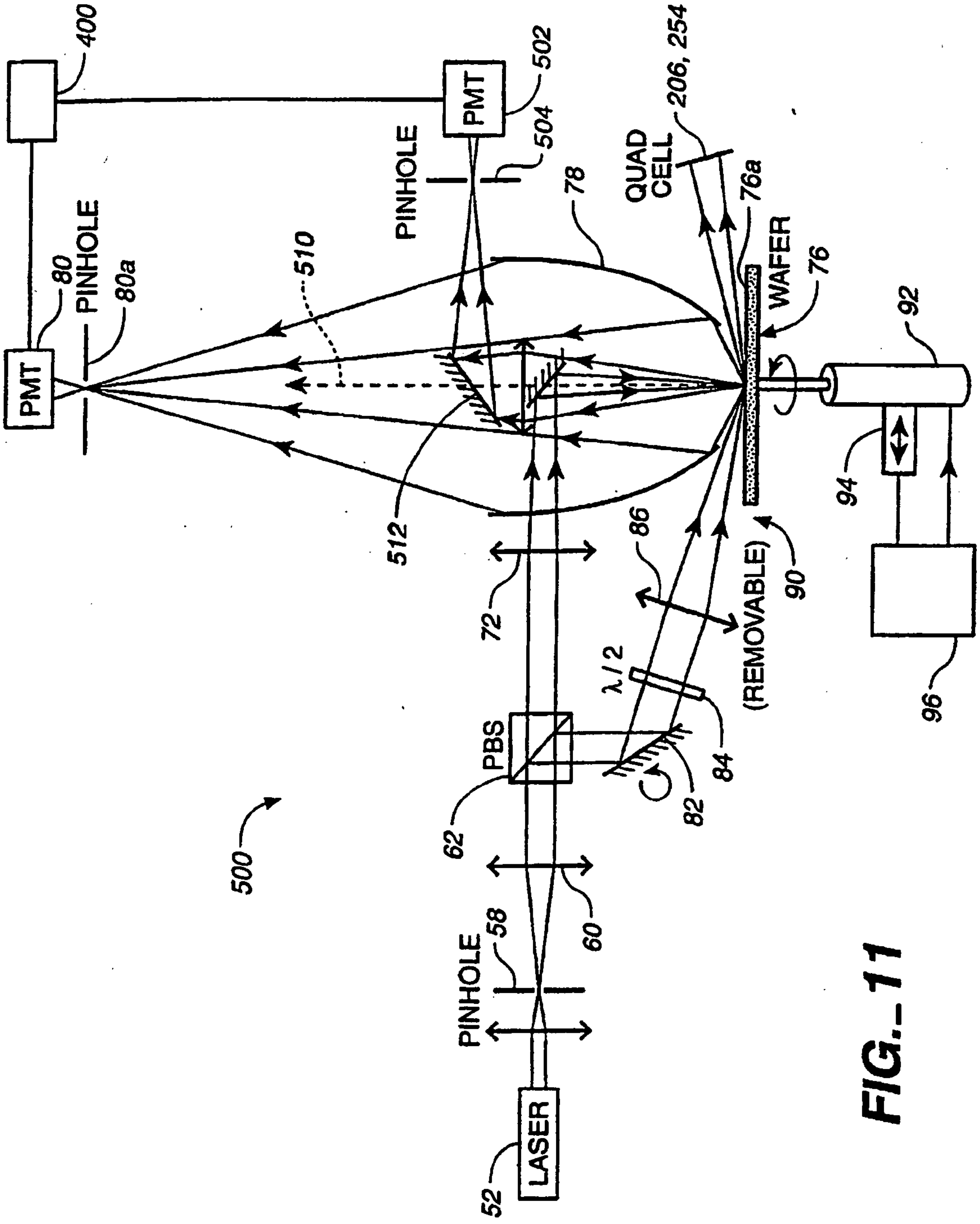
PMT
PMT
PINHOLE
PINHOLE
QUAD CELL
206, 254
WAFER
(REMOVABLE)
λ/2
PBS
PINHOLE
PINHOLE
LASER

FIG._11

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